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Environmental Benefits of Restoring Sediment Continuity to the Kansas River

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) summarizes the environmental benefits that could be gained by restoring sediment continuity from the Kansas River watershed to the Kansas River by passing sediment through, rather than trapping sediment in, large Federal reservoirs. The effort was conducted by the U.S. Army Engineer District, Kansas City (NWK), and supported by the U.S. Army Corps of Engineers (USACE) Regional Sediment Management (RSM) Program. The section of this CHETN titled "In-Reservoir Effects of Sediment Accumulation" explains the water quality and ecological effects of reservoir aging by sediment accumulation. The section titled "Downstream Channel Effects" cites specific ecological effects from unnaturally low turbidity levels in the Kansas River. The section titled "Sediment Quality and Timing" describes the natural quantity and timing of sediment delivery that can be used as a reasonable upper bound for all sediment recharge activities. Socioeconomic considerations, including impacts to water supply, flood risk management, recreation, and navigation support have been addressed by others and are not discussed here. This technical note documents multiple environmental benefits that could result from reservoir sediment management that removes sediment from major Federal reservoirs and recharges sediment to the Kansas River. The same may be true for other USACE reservoirs and their downstream receiving channels in historically turbid systems.

INTRODUCTION: Excess sedimentation is a major issue in flowing waters around the world with well-documented negative effects (Wood and Armitage 1997; Karr and Yoder 2004). However, as noted by the National Research Council (2011), "Not all sediments and all rivers are the same." Sediment should not be universally considered as a pollutant, especially in historically turbid river systems. To the contrary, the transport of sediment is a natural function in river ecosystems, and a lack of sediment can be deleterious to aquatic habitats and organisms (National Research Council 2011). Dam construction, as discussed by Wohl et al. (2015), Juracek (2014), Kondolf et al. (2014), and the National Research Council (2011), is one of the primary factors contributing to unnatural decreases in downstream sediment transport and resulting in negative impacts to the environment. As summarized by Kondolf et al. (2014), approximately 3–4 billion tons of sediment are trapped in reservoirs worldwide each year. A notable example of sediment trapping by dams is Glen Canyon Dam on the Colorado River, where dam construction reduced available fine grain sediment by approximately 81%–85% at a location 15 miles downstream of the dam (Topping et al. 2000). On the Missouri River, the annual suspended sediment load at Yankton, SD, just downstream of Gavins Point Dam, decreased from approximately 140 million tons/year from 1940 to 1952 to approximately 2 million tons per year, on average, from 2001 to 2008 (USACE 2011).

Construction of six major Federal reservoirs (Harlan County Lake, Waconda Lake, Tuttle Creek Lake, Milford Lake, Wilson Lake, and Kanapolis Lake) has dramatically influenced the Kansas River, a predominantly sand-bed river extending approximately 170 miles downstream from the confluence of the Smoky Hill and Republican Rivers near Junction City, KS, to the Missouri River in Kansas City, KS (Figure 1).

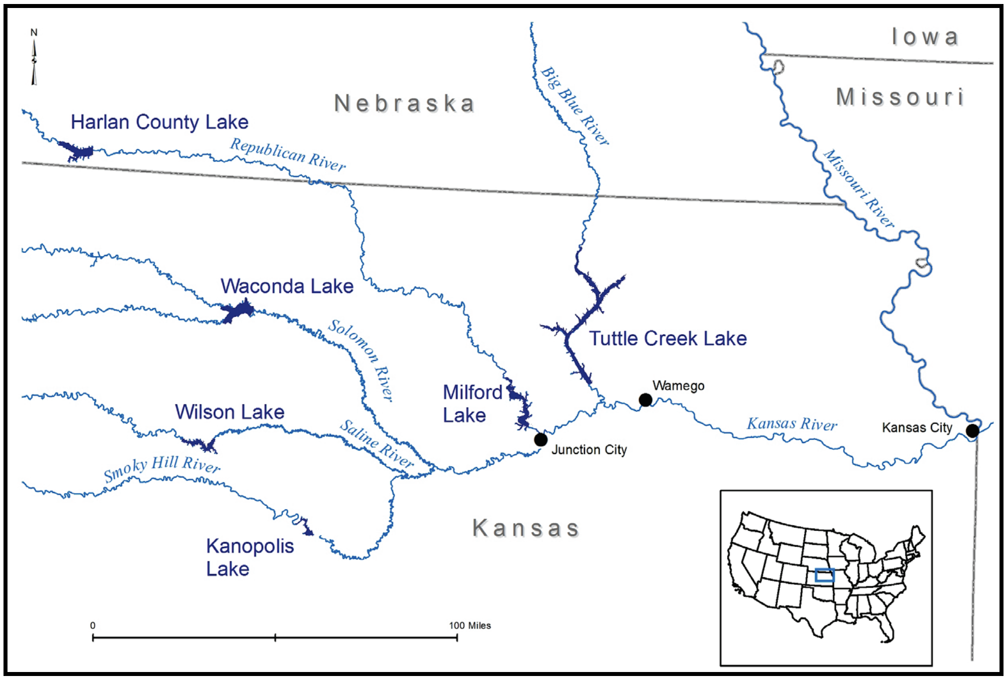

Figure 1. Six major Federal reservoirs on the Kansas River upstream of Wamego, KS.

Beginning in the 1960s, large Federal dams were constructed on Kansas River tributaries that dramatically altered the hydrologic and sediment transport process of the river. These dams have decreased annual suspended sediment load from approximately 44 million tons/year to approximately 13 million tons/year (National Research Council 2011). This technical note documents water quality and ecological effects of reservoir aging by sediment accumulation, specific ecological effects from unnaturally low turbidity levels in the Kansas River, and natural (without reservoir) quantity and timing of sediment delivery to the Kansas River.

IN-RESERVOIR EFFECTS OF SEDIMENT ACCUMULATION: Sediment accumulation can increase eutrophication and impair water quality (one of the authorized purposes of many USACE reservoirs). Loss of storage capacity in a reservoir due to sedimentation increases the frequency and severity of water quality problems and associated biological impairment. This section summarizes research literature on how sediment accumulation impacts reservoir water quality and ecology and provides a summary of water quality in Milford Lake and Tuttle Creek Lake, two large reservoirs on the Kansas River system that are affected by sediment accumulation.

Concentration, resuspension, and bioperturbation. As reservoirs age, decreased dilution of incoming sediment loads, and resuspension and bioperturbation of bed sediments, increase turbidity and internal nutrient loading. The suspended sediment concentration and turbidity in a reservoir is partially a function of the incoming sediment load being diluted with ambient lake water. As a reservoir loses storage to sediment accumulation, less ambient lake water is available for diluting incoming sediment and nutrient loads, leading to higher turbidity and nutrient concentrations especially following large inflow events. Additionally, shallow reservoirs are susceptible to wind-generated sediment resuspension and increased bioperturbation (Søndergaard et al. 2008), which promotes internal loading, high light attenuation, and excessive algal growth (Hellström 1991; Bengtsson and Hellström 1992; Søndergaard et al. 1992). Increased internal loading can lead to decrease in beneficial algae populations and production of blue-green algae, also called cyanobacteria (Chowdhury et al. 2006).

Nutrient ratios and fish kills. Sediment accumulation in a reservoir affects nitrogen and phosphorous concentrations differently. Nitrogen tends to remain suspended in the water column and moves through a reservoir with the water. In contrast, phosphorous binds to sediment particles that can settle to the bottom of a reservoir. The phosphorus is released from the sediment through anoxic redox reactions and through physical perturbation and resuspension of the sediments. In shallow reservoirs, these processes lead to low total nitrogen-to-total phosphorous (TN:TP) ratios, which favors the growth of blue-green algae (Grantz et al. 2014). Some species of blue-green algae produce toxins that pose a health risk to people and animals.

Additionally, increased turbidity from suspended sediment inhibits the growth of phytoplankton that make up the base of the food chain and aquatic vascular plants that provide habitat for other aquatic species (Wetzel 2001; Donohue and Molinos 2009). Reduced depth and increased turbidity can also impact heat distribution and cause increased temperature variability. High biological oxygen demand related to algae populations can drastically reduce dissolved oxygen concentrations, leading to an increased risk of fish kills (Miranda et al. 2001).

Fish species. Changing or declining water quality conditions that alter algae and plant species composition leads to trophic changes within reservoir ecosystems, affecting phytoplankton, aquatic plants, aquatic invertebrates, and ultimately fish species. Eutrophication increases algae production as measured by increases in chlorophyll *a* and causes a shift in fish species composition from desirable sport fish (primarily piscivores) to less desirable benthivores (Egertson and Downing 2004).

In many aging reservoirs, there are increases in biomass of common carp (*Cyprinus carpio*), a benthic species. Carp are non-native fish that thrive in degraded habitat and poor water quality conditions associated with shallow eutrophic reservoirs. Carp disturb bed sediments when feeding, increasing turbidity within the water column (Meijer et al. 1990; Breukelaar et al. 1994; Lougheed et al. 1998). Carp also increase nutrient concentrations in lakes directly through excretion (Lamarra 1975). Zambrano et al. (2001) described drastic reductions in benthic invertebrate diversity and biomass resulting from common carp introductions, noted greater impacts in shallow eutrophic lakes due to greater carrying capacity of carp, and noted more pronounced water quality impacts from carp bioperturbation.

Other studies (Miller 2006) have found decreased invertebrate diversity but increased biomass of mud-burrowing chironomids and ephemeropterans. Gizzard shad (*Dorosoma cepedianum*) is a benthic detritivore that benefits from increased turbidity and eutrophication process. Similar to carp, gizzard shad behavior and feeding activity lead to bioperturbation of lake bed sediment and resuspension of nutrients. Gizzard shad and other detritivorous fish excrete nutrients with a low nitrogen-to-phosphorous ratio, primarily composed of soluble reactive phosphorus (Shaus et al. 1997), which favors blue-green algae and may alter the algae species composition if excrement mass is biologically significant. (Lamarra 1975; Drenner et al. 1986; Brabrand et al. 1990). Carp and gizzard shad populations add to the poor water quality in which they thrive. Additional fish species that benefit from eutrophic conditions of increased total suspended solids, shallow mean depth, high conductivity, and high chlorophyll *a* concentrations include white crappie (*Pomoxis annularis*) and black bullhead (*Ameiurus melas*) (Egertson and Downing 2004).

Water quality conditions in Milford Lake and Tuttle Creek Lake. Milford Lake and Tuttle Creek Lake have a recent history of extremely high total phosphorus and soluble reactive phosphorus concentrations, exceeding Carlson's Hypereutrophic Status threshold (Carlson 1977) in all years 1996 to 2014 (Figures 2 and 3). Under these conditions, algae proliferation is likely when light availability is sufficient (Carlson 1977). Algae proliferation has occurred on Milford Lake, but low-light penetration due to high turbidity levels has limited algae growth at Tuttle Creek Lake.

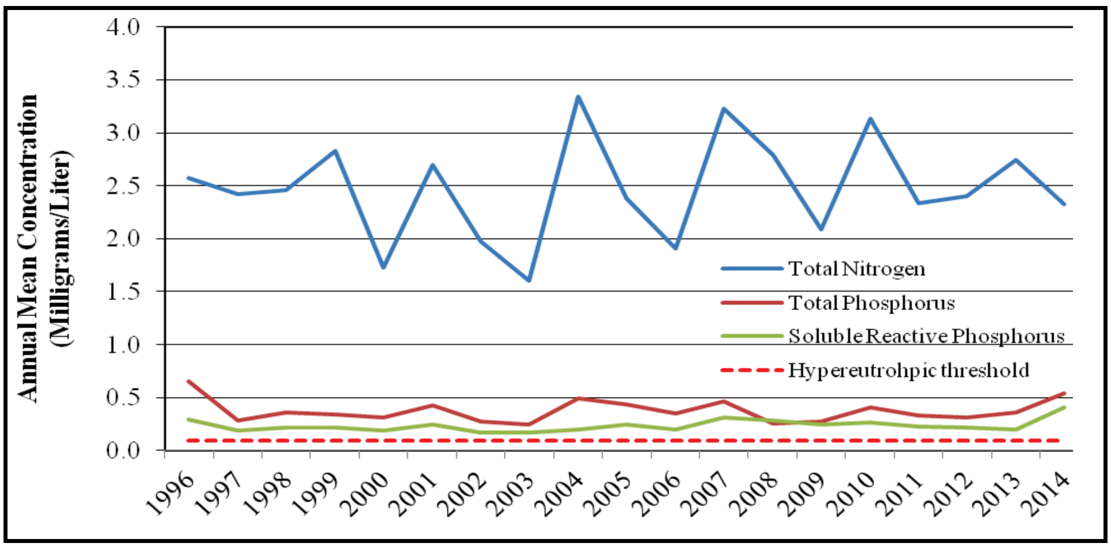

Figure 2. Milford Lake nutrient concentrations from 1996 to 2014. Data are from a long-term monitoring station located near the inflow. The hypereutrophic threshold is equal to 0.096 milligrams/liter (mg/L).

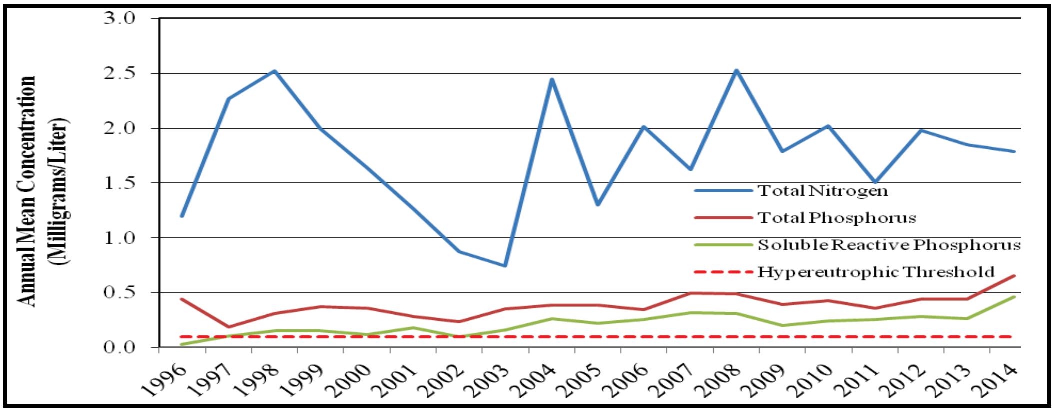

Figure 3. Tuttle Creek Lake nutrient concentrations from 1996 to 2014. Data are from a long-term monitoring station located near the inflow. The hypereutrophic threshold is equal to 0.096 mg/L).

Milford Lake and Tuttle Creek Lake have had very low (i.e., less than 12) TN:TP ratios (Figure 4) which favor blue-green algae over other algae and plant communities. Milford Lake typically has a lower TN:TP ratio than Tuttle Creek Lake. This is due to high algae production and bioattenuation of nitrogen at Milford Lake while Tuttle Creek Lake is light limited because of high concentrations of suspended sediment and has very little algae production. Both Milford Lake and Tuttle Creek Lake typically have slightly higher TN:TP ratios near the dams as noted by differences in lower lake and upper lake sites in Figure 4. Lake conditions seem to have led to decreasing TN:TP ratio at both lakes since 2011, and blue-green algae blooms and public health warnings have increased in frequency at Milford Lake since 2011.

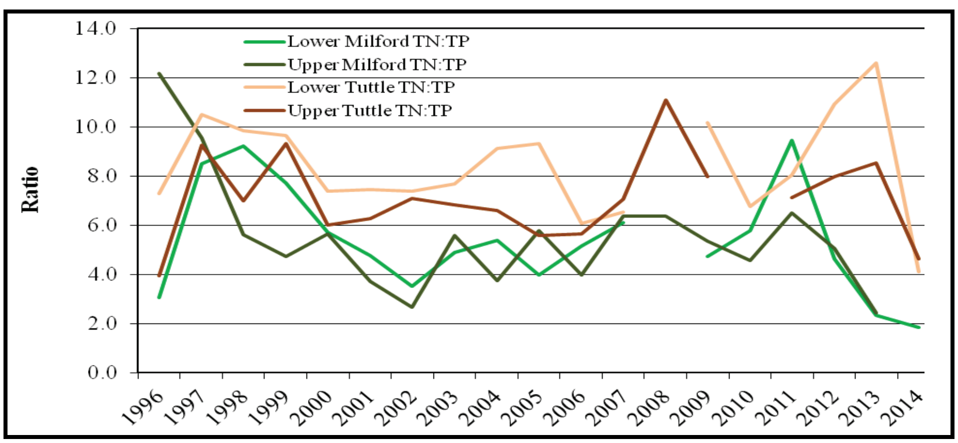

Figure 4. Milford Lake and Tuttle Creek Lake nutrient ratios. Locations identified as “Upper” are from a location in the upstream portion of the reservoir, and those identified as “Lower” are from a location near the dam.

In Milford Lake, blue-green algae often comprise 95% of the phytoplankton community from July–September[1] NWK collected phytoplankton samples from Milford Lake, which showed a high percent of blue-green algae in August 2014 (Figure 5) while Tuttle Creek Lake had very low-density algae cell counts with populations comprised primarily of diatoms (Figure 5).

[1]Kansas Department of Health and Environment, personal communication, 2014.

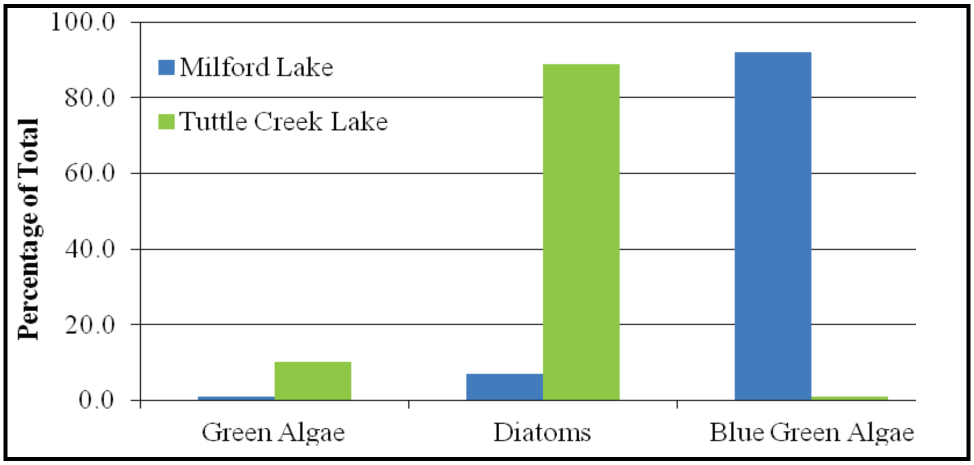

Figure 5. Phytoplankton samples collected in August 2014 from Milford Lake were primarily composed of blue-green algae while those collected from Tuttle Creek Lake were primarily composed of diatoms.

Loss of storage in reservoirs due to sediment accumulation accelerates eutrophication and impairs water quality in several ways, including increased turbidity, increased resuspension and bioperturbation, and decreased TN:TP ratio. These effects lead to an increase in the magnitude and frequency of algae blooms and fish kills and a shift in fish species composition from desirable sport fish (primarily piscivores) to less desirable benthivores.

As sediment continues to accumulate in Milford Lake and Tuttle Creek Lake, low TN:TP ratios are expected to worsen. At Milford Lake, this will lead to increased blue-green algae blooms with an expected increase in the frequency of public health warnings. At Tuttle Creek Lake, insufficient light penetration may continue to prevent such blue-green algae blooms and associated problems.

DOWNSTREAM CHANNEL EFFECTS: Altered sediment transport processes not only affect physical processes in rivers but also biological communities. Many native fishes in rivers of the Great Plains, including the Kansas River, are adapted to extreme changes in flow and turbidity (Davis and Miller 1967). Adaptations include relatively small optic lobes (Davis and Miller 1967) and well-developed electro-sensory and chemo-sensory organs to navigate, locate food, and avoid predation (National Research Council 2011). For example, these species have a greater number of internal and external taste buds compared to sight-feeding fishes typically found in clear water environments (Davis and Miller 1967). Given these adaptations, the 70% reduction of sediment in the Kansas River has impacted the fish community (Haslouer et al. 2005). Gido et al. (2010) evaluated fish community composition on the lower Kansas River by probability of occurrence between 1947 and 2003 and documented the decline of several native species including shoal chub, plains minnow, flathead chub, river shiner, and carmine shiner during this period. Several other species (e.g., silver chub, sturgeon chub, and western silvery minnow) were present initially but absent during later collections. As these native fishes declined, Gido et al. (2010) also documented an increase in fishes that are less tolerant to turbid water, including bluntnose minnow, suckermouth minnow, and sand shiner. Similarly, Bonner and Wilde (2002) found that reduced suspended sediment loads in prairie rivers resulted in the replacement of fish species that were historically found in highly turbid rivers by fishes that are more dependent on sight feeding. It has been noted that cyprinids, including many declining species on the Kansas River, are especially sensitive to reductions in sediment and turbidity (Quist et al. 2004). The State of Kansas has designated critical habitat in the Kansas River for several state-listed threatened and endangered species including the plains minnow, shoal chub, sturgeon chub, and silver chub.

Given the dramatic reduction in sediment load following the construction of dams, native fishes in the Kansas River may benefit from sediment-oriented restoration measures. However, a number of factors may affect the ability of these potential actions to measurably benefit the native fish community. For example, a threshold level of sediment may be required before the native fish community responds (i.e., small sediment inputs may not sufficiently increase turbidity levels). Timing and duration may also be important as temporary increases in sediment load may not translate into measurable benefits, or if measurable, the benefits may be short lived. Other factors unrelated to turbidity and suspended sediment, such as non-native species, could also be impacting native fish populations. It is also possible that lack of changes in flow regime may limit benefits despite increased sediment inputs. That said, any increase in suspended sediment is likely an improvement to present conditions for native fishes.

SEDIMENT QUANTITY AND TIMING: Efforts to restore the sediment load to the Kansas River should limit the increase in sediment load to the natural *no dam* condition. Table 1 lists the annual sediment trapping in Federal reservoirs upstream of Wamego, KS. As reflected in Table 1, these six Federal reservoirs trap 8,070 acre-feet (acre-ft) of sediment annually that would otherwise flow into the Kansas River above Wamego, KS (Figure 1). Tuttle Creek Lake alone traps over half of the sediment.

Table 1. Sediment trapping in Federal reservoirs on Kansas River tributaries upstream of Wamego, KS.

Reservoir	Agency	Sediment Trapping (acre-ft/year)
Tuttle Creek	USACE	4741
Milford	USACE	984
Kanapolis	USACE	566
Wilson	USACE	279
Harlan County	USACE	814
Wakunda	Bureau of Reclamation	686

The annual rates given in Table 1 are based on repeat bathymetric surveys and represent long-term averages. Sufficient monitoring data exist for Tuttle Creek Lake (the largest of the Kansas River reservoirs) to define the typical timing as well as the quantity of sediment delivery. This represents the natural timing of sediment delivery to the Kansas River from the Big Blue River watershed, which can provide insight into the timing of natural sediment loads had there been no dams in place. The following five U.S. Geological Survey (USGS) stream flow gages were used for this analysis:

- Gage #06882510, Big Blue River at Marysville, KS (Tributary Gage)
- Gage #06884400, Little Blue River near Barnes, KS (Tributary Gage)

- Gage #06885500, Black Vermillion River near Frankfort, KS (Tributary Gage)
- Gage #06887000, Big Blue River near Manhattan, KS (Gage Immediately Downstream of Dam on Big Blue River)
- Gage #06887500, Kansas River at Wamego, KS (Gage on Kansas River Downstream of Tuttle Creek Lake).

Sediment rating curves were generated for these gages using measured data to calculate daily sediment loads based on average daily discharges. The gaged tributaries to Tuttle Creek Lake account for 8,538 square miles of the reservoir's 9,640 square mile drainage area. For the purpose of this study, sediment loads were scaled by 1.13 (9,640/8,538) to account for the un-gaged drainage area. Figure 6 shows the average monthly suspended sediment loads flowing into the reservoir, passing through the reservoir, and being trapped in the reservoir from 1984 to 2014. Values calculated from the incoming sediment loads approximately match the sedimentation rate calculated using repeat bathymetric surveys, as listed in Table 1.

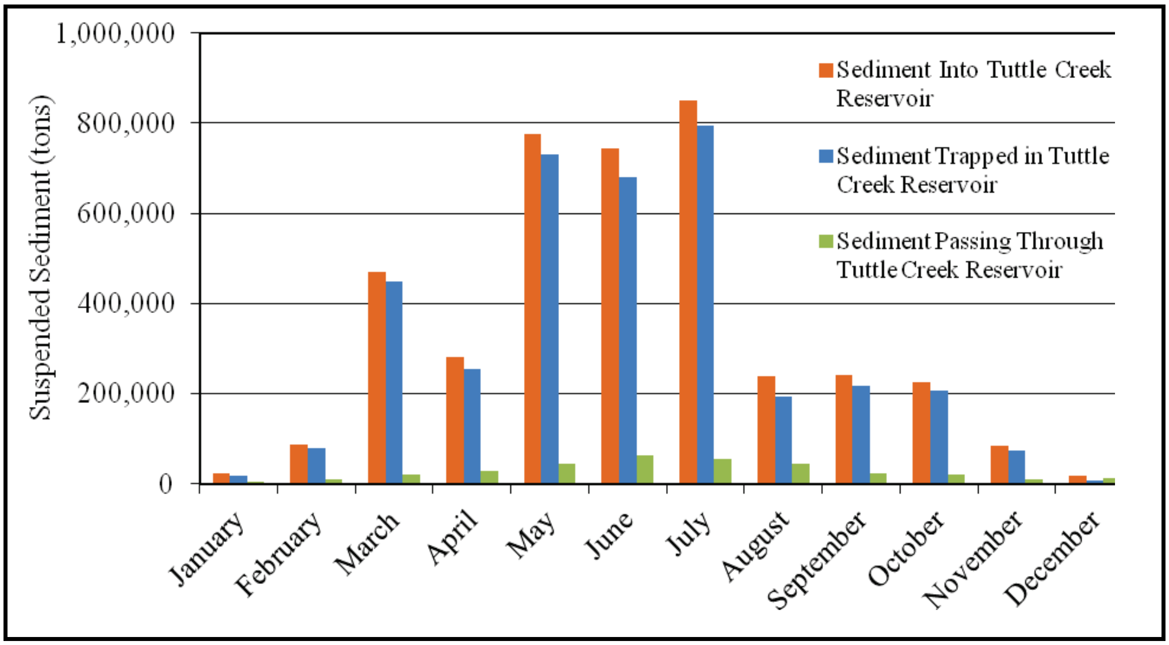

Figure 6. Sediment into, trapped, and passing through Tuttle Creek Reservoir.

Figures 7 and 8 illustrate how the sediment loads and concentrations in the Kansas River at the Wamego gage would increase over current levels if all the sediment flowing into Tuttle Creek Lake were passed through to the Kansas River. Passing all the incoming sediment on an annual basis would increase the sediment loading at Wamego by 60% over current levels. The values in Figures 7 and 8 represent the natural contribution from the Tuttle Creek Lake (Big Blue River) watershed.

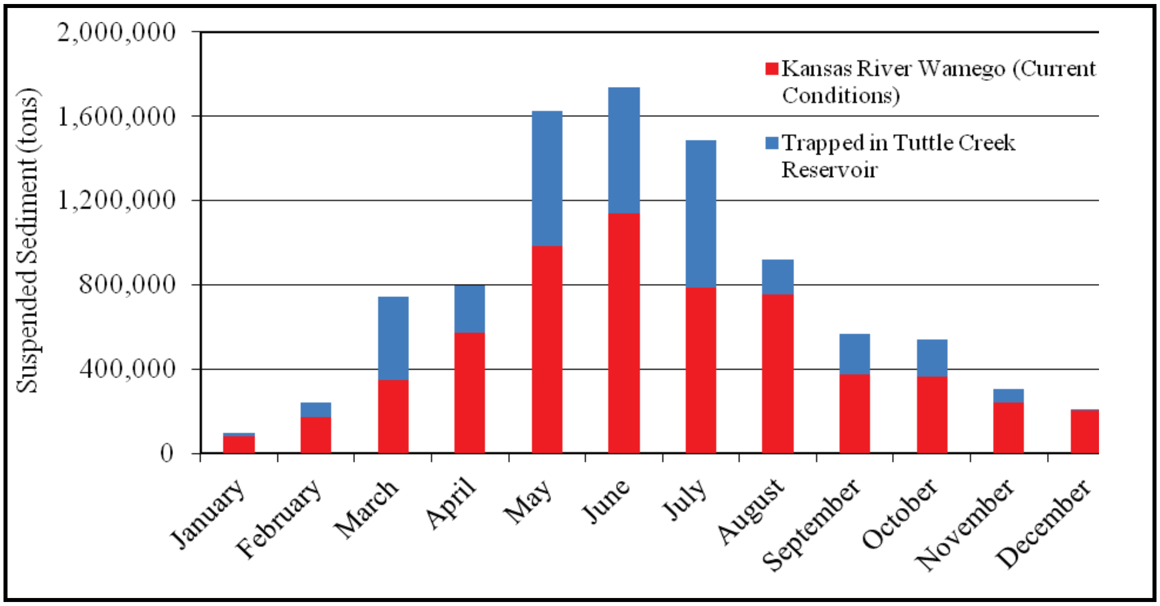

Figure 7. Sediment load deficit in the Kansas River due to Tuttle Creek Lake trapping sediment.

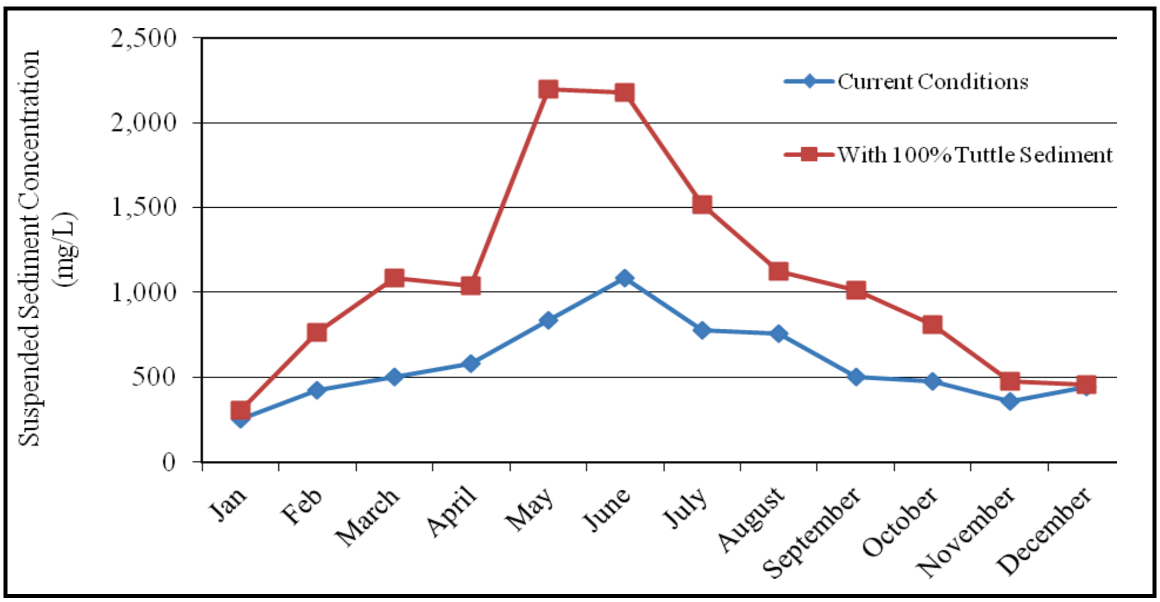

Figure 8. Suspended sediment concentration deficit in the Kansas River due to Tuttle Creek Lake trapping sediment.

The natural (no dams) sediment loading and concentrations in the Kansas River (including sediment loads being trapped behind the five major federal dams) are presented in Figures 9 and 10. The values in Figures 9 and 10 were computed by taking the monthly pattern in sediment delivery evident at Tuttle Creek Lake and scaling it according to the average annual sediment accumulation rates given in Table 1. Note that these are monthly averages. The sediment loads and concentrations may exceed these values during individual high-water events.

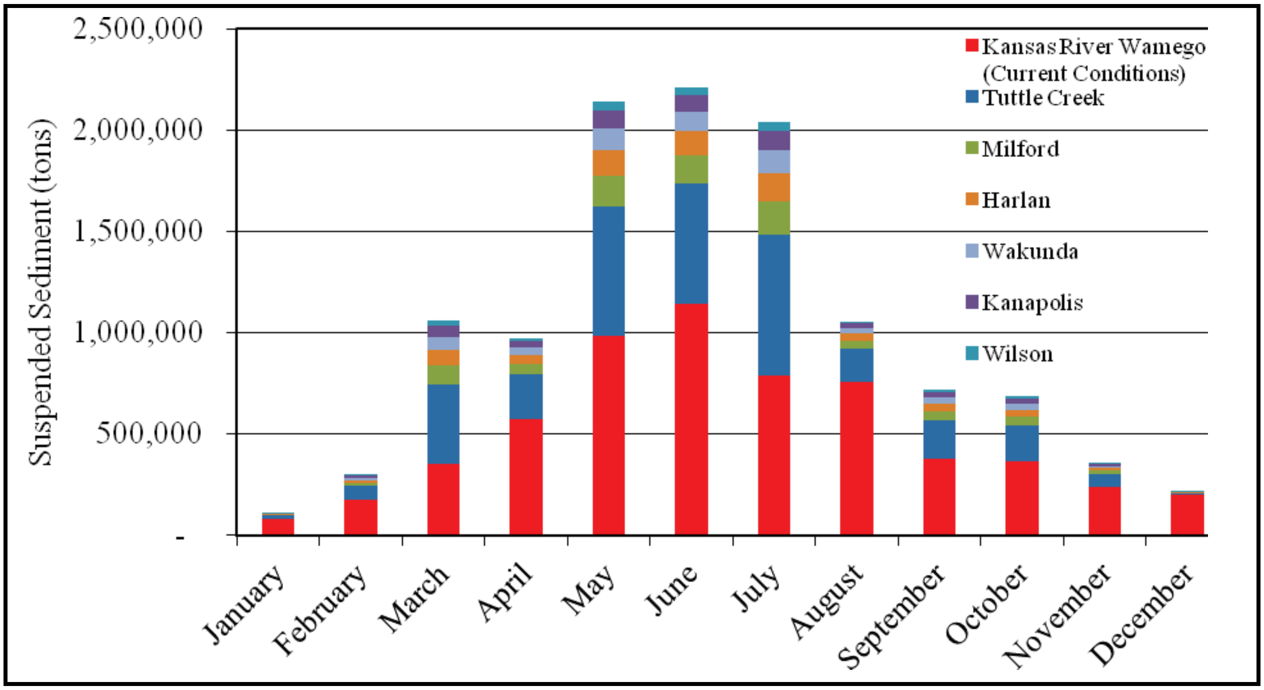

Figure 9. Sediment load deficit in the Kansas River due to sediment trapping in six USACE reservoirs.

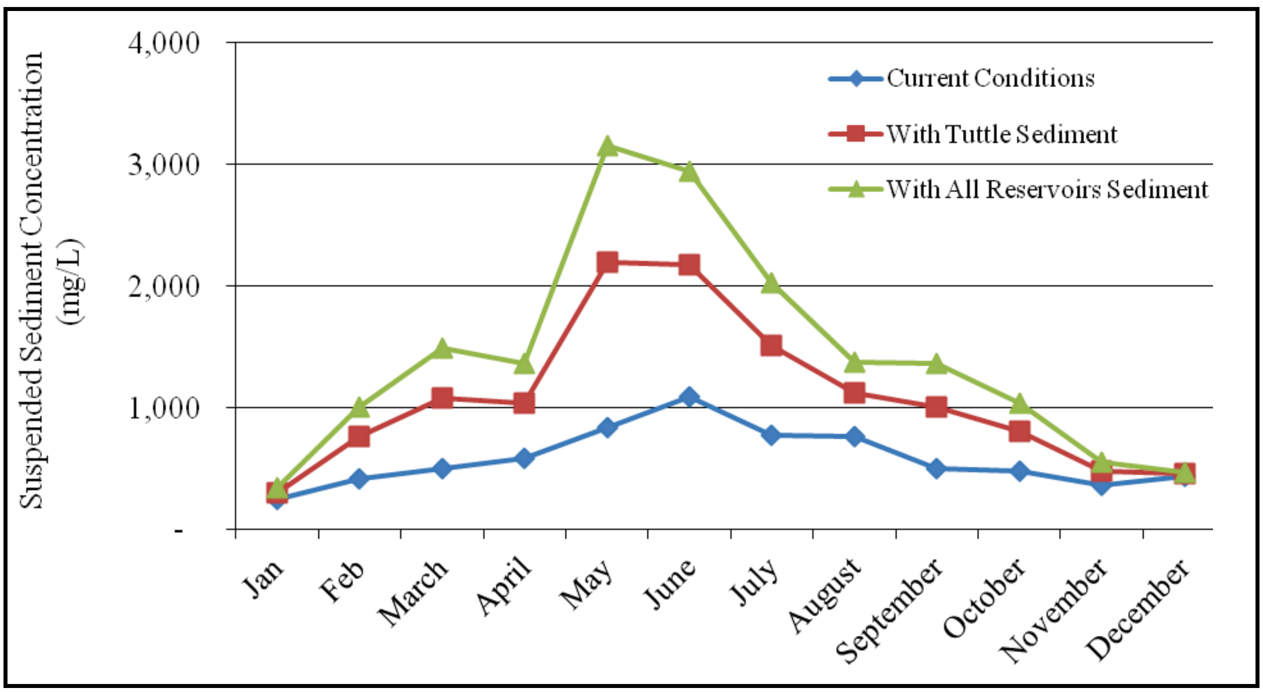

Figure 10. Suspended sediment concentration deficit in the Kansas River due to sediment trapping in six USACE reservoirs.

CONCLUSIONS: Sediment trapping in six major Federal reservoirs on the Kansas River has environmental consequences for both the in-reservoir and downstream channel environments.

Loss of storage in reservoirs due to sediment accumulation accelerates eutrophication and impairs water quality by increasing turbidity, increasing resuspension and bioperturbation, and decreasing the TN:TP ratio. These effects increase the magnitude and frequency of algae blooms and fish kills, and shift the fish species composition from desirable sport fish (primarily piscivores) to less desirable benthivores.

Lack of turbidity in the Kansas River caused by reservoir sediment trapping has impaired habitat for several native Kansas River fishes, including the state-listed threatened and endangered shoal chub and plains minnow. While lack of turbidity may not be the only factor leading to a decline in these native fish populations, an increase in suspended sediment would represent an improvement to current conditions for native fishes.

Federal reservoirs on the Kansas River upstream of Wamego trap an estimated 8,070 acre-ft of sediment per year, most of which would be delivered to the Kansas River from March to October. Provided the timing of sediment delivery mimics the natural timing, and the combined inputs from all reservoir sediment management/restoration projects do not exceed the reasonable upper bound presented in this technical note, restoring sediment continuity by passing sediment to the Kansas River represents a benefit to both the in-reservoir and downstream channel environments.

ADDITIONAL INFORMATION: This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared as part of the USACE Regional Sediment Management (RSM) Program by John Shelley, Marvin Boyer, Jesse Granet, and Aaron Williams of the U.S. Army Engineer District, Kansas City (NWK). Additional information regarding the RSM Program can be found at the RSM website http://rsm.usace.army.mil.

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